

Holly STATCOM – FACTS to replace critical generation, operational experience

A. Oskoui, B. Mathew, *Member, IEEE*, J.-P. Hasler, M. Oliveira, *Member, IEEE*,
T. Larsson, *Member, IEEE*, Å. Petersson, E. John, *Member IEEE*

Abstract—Austin Energy plans to decommission an old oil- and gas-fired plant near downtown Austin, Texas, USA. In addition to providing the generation capacity, an important reason the four-unit Holly plant has been kept in operation is to stabilize the voltage on the transmission system. Retirement of the power plant without a reliable dynamic reactive source would have a negative impact on the transmission system voltage stability. A special requirement in Austin Energy’s case is recovery from voltage sags where a fast response is necessary at low voltages, i.e. transient voltage recovery. Furthermore, physical limitations related to aesthetics, electromagnetic field emissions, and audible noise had impact on the solution to be implemented.

Transmission planning studies determined that the voltage requirements could be met using a STATCOM. This paper provides details on the background, an overview of the STATCOM technology, and shows results from the first period of operation of the Holly STATCOM, delivered by ABB.

Index Terms — AC-DC power conversion, Converters, Insulated gate bipolar transistors, Power conditioning, Power control, Power system dynamic stability, Static VAR compensators, Pulse width modulation, STATCOM, SVC Light, Transient voltage recovery, Voltage control, Voltage source converter

I. NOMENCLATURE

FACTS	Flexible AC Transmission System
IGBT	Insulated Gate Bipolar Transistor
PWM	Pulse Width Modulation
STATCOM	STATIC var COMPensator
VSC	Voltage Source Converter

II. INTRODUCTION

AUSTIN Energy plans to decommission an old oil- and gas-fired power plant near downtown Austin, Texas, USA. The power plant was constructed in the 1960s. In addition to providing the generation capacity, an important reason the plant has been kept in operation is to stabilize the voltage on the transmission system. Retirement of the power plant without a reliable dynamic reactive source would have a

negative impact on the transmission system voltage stability. Flexible AC Transmission System (FACTS) technology was considered as a possible solution for the problem. A special requirement in Austin Energy’s case is the recovery from voltage sags where a fast response is necessary at low voltages. Physical limitations of the urban site included low electro-magnetic fields and audible noise emissions, which were specified as special requirements of the installation.

An initial study showed that the needs could be met using a compact STATic COMPensator (STATCOM). ABB won the bid in competition with other suppliers. ABB’s STATCOM solution has the brand name SVC Light[®], indicating the close relation to ABB’s HVDC Light[®] as both are based on Voltage Source Converter (VSC) technologies. A STATCOM is specially suited for supplying full compensating current at very low AC network voltages and has the ability to compensate for unbalances. The STATCOM design features also include a minimum footprint and effective electro-magnetic screening, both of which were required in this application.

III. STATCOM TECHNOLOGY

The principal component of the STATCOM is the VSC. This technology has been used for many years primarily in motor drives. The last years, however, an increasing number of plants for considerably higher power and voltage, based on the VSC technology have been built for both industrial [1-4] and power system [5-8] applications. The Holly STATCOM is based on ABB’s SVC Light platform, a concept utilizing the so-called Neutral Point Clamping (NPC) converter, a three-level converter topology that combines high controllability with robustness against grid disturbances. In addition, the power losses are moderate thanks to the employed switching frequency.

For converter control and modulation, different switching schemes are available. ABB has chosen a control scheme based on Pulse Width Modulation (PWM). The high frequency switching control, which for the Holly STATCOM is set at 21 times the fundamental frequency, provides a fast and extremely robust VSC control. This is particularly required during severe faults on the power system. Moreover, compensation of voltage unbalance can be achieved without the installation of low order harmonic filters. To allow for use of a compact high-power VSC with sufficiently high

A. Oskoui (e-mail: arastou.oskoui@austinenergy.com) and B. Mathew (e-mail: biju.mathew@austinenergy.com) are with Austin Energy, Austin, TX, USA

J.-P. Hasler (e-mail: jean-philippe.hasler@se.abb.com), M. Oliveira (e-mail: marcio.oliveira@se.abb.com), T. Larsson (e-mail: tomas.x.larsson@se.abb.com) and Å. Petersson (e-mail: ake.n.petersson@se.abb.com) are with ABB, Västerås, SE-721 64, Sweden

E. John (email: eric.john@us.abb.com) is with ABB, Raleigh, NC, USA

switching frequency, the Insulated Gate Bipolar Transistor (IGBT) is the most suitable component available. Using IGBTs and high frequency PWM switching assures excellent performance during network faults. Network faults have proved to be quite troublesome for thyristor based (GTO, IGCT) solutions.

The VSC inherently has a symmetrical current operating range. This is favorable from a STATCOM point-of-view as the system can be optimized for fast response both in the inductive (i.e. over-voltage suppression) as well as capacitive (i.e. under-voltage support) modes while minimizing the losses. Passive filters provide harmonic filtering for the higher harmonic frequencies generated by the converter, and offset the STATCOM range some 15 Mvar in the capacitive range. Furthermore, additional control of external devices such as mechanically switched capacitor banks and tap changers can be incorporated in the control system. Specifically for the Holly STATCOM application, control of an On Line Tap Changer (OLTC), three 138 kV 31.2 Mvar capacitor banks and one 69 kV 31.2 Mvar capacitor bank have been incorporated in the control system. For future projects, it is also possible to control other types of equipment such as for instance shunt reactors.

IV. THE HOLLY STATCOM INSTALLATION

A. STATCOM Rating

The power plant to be retired is located on Holly Street near downtown Austin. The STATCOM is partially built on top of a reinforced old oil tank near the Holly power plant, at the Pedernales substation. The STATCOM consists of a VSC inherently symmetrically rated at ± 95 MVA and 15 Mvar of filters seen from the Pedernales 138 kV bus. In total this gives an operating range from 80 Mvar inductive reactive power to 110 Mvar capacitive reactive power. There are also the three 138 kV capacitor banks each rated at 31.2 Mvar for providing steady-state reactive power support to the grid.

Including the three 138 kV capacitor banks, the reactive power range is 80 Mvar inductive to just above 200 Mvar capacitive. The dynamic portion of this is two times the VSC rating of 95 Mvar, or 190 Mvar.

B. Main circuit description

Figure 1 shows a simplified single line diagram of the Holly STATCOM (including the dual redundant transformers and the three 138 kV capacitor banks) and Figure 2 shows the layout. The entire installation can be seen in the photo shown in Figure 3. It is worth noting that the entire secondary voltage circuit (at 32 kV) is placed indoors. As always the converters are indoor-type of equipment, but in this installation the phase reactors and the passive harmonic filters are enclosed as well. The principal reason for enclosing the phase reactors and the passive harmonic filters is the need for screening, both electromagnetic and acoustic. However, the enclosure also made it possible to meet requirements on varmint proofing.

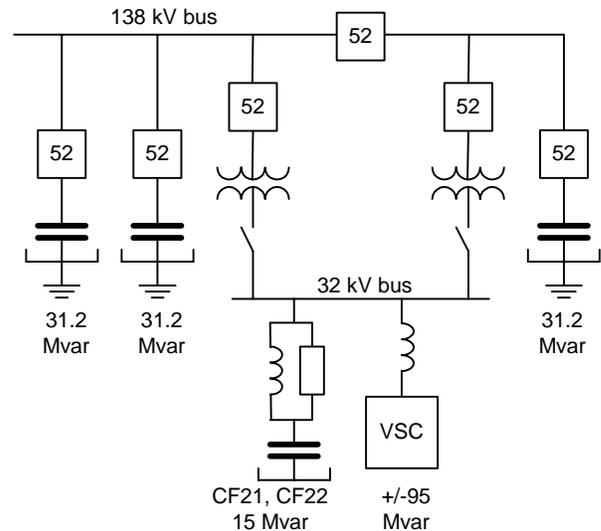


Fig. 1. Holly STATCOM single line diagram.

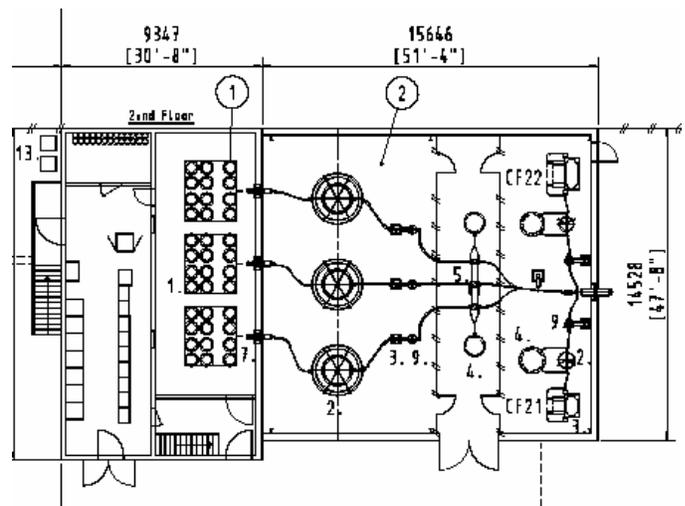


Fig. 2. Holly STATCOM layout

- 1) Valve hall
- 2) Enclosed 32 kV equipment

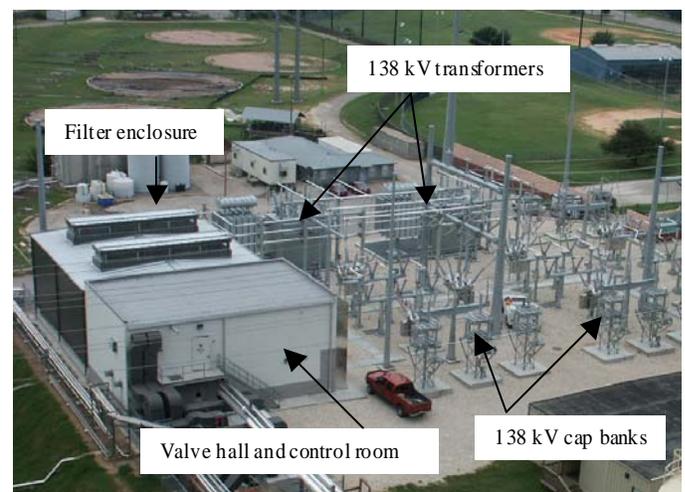


Fig. 3. Holly STATCOM

C. Operating strategy

The STATCOM utilizes the ABB MACH2 control system, a common control platform used for all ABB FACTS and HVDC Projects. The MACH2 controller inherently has the capability to automatically take actions for switching in and out the three 138 kV mechanically switched capacitor banks. This operating strategy forces the fixed capacitor banks to be the major producer of reactive power support during slow varying conditions in the system. The strategy leaves the STATCOM ready to rapidly respond with dynamic reactive power support to disturbances occurring during power system contingencies. This applies to both over-voltage suppression and under-voltage support.

The STATCOM control system also switches an existing 69 kV capacitor bank as well as the tap-changer position of a 69/138 kV auto-transformer. These voltage control mechanisms are slower than the switching controls of the 138 kV banks and are designed to improve the slow voltage profile on the 69 kV system and to minimize reactive power flow through the auto-transformer.

D. Site considerations in the design

The local site conditions included a residential neighborhood and as such the STATCOM design had to meet strict requirements on electromagnetic emissions and acoustic noise. The extended building proved to be a cost effective solution for screening and it also provided excellent varmint proofing of the installation. In addition to enclosing the harmonic filters and phase reactors, the transformers utilize a two-wall design for audible noise reduction.

In addition to residential housing, the aerial photo in Figure 3 shows that the STATCOM is in the close proximity of existing facilities (e.g. piping) belonging to the Holly power plant. It became a true design challenge to fit all of the equipment in the space available. However, the Holly STATCOM installation is an example that a single-converter STATCOM scheme can be built considerably smaller than its nearest relatives in the FACTS family, i.e. the multi-converter based STATCOM or the SVC.

V. SIMULATIONS COMPARED TO REALITY

In the Holly STATCOM project, a number of studies were performed to verify the STATCOM performance. The studies covered for instance STATCOM dynamic performance with a focus on voltage sag ride-through and low AC voltage conditions, capacitor bank switching with back-to-back switching and outrush currents, transmission system power flow, harmonics, sound propagation and reliability. The simulations were mainly performed in PSCAD, PSS/E and other proprietary software. The results were seamlessly incorporated in the system design. Many of the simulated results were also verified in the field during extensive system tests on site. Some details are given in the remainder of the paper.

Before commissioning of the equipment, a complete STATCOM model was built in a time-domain simulation

program for preliminary evaluation of the control functions implemented in the Holly STATCOM. These tests were later repeated during factory validation tests and during commissioning.

An example of these tests is verification of the response of the STATCOM current controller and is shown in the following plots. In this case, the STATCOM was operated in open-loop, i.e. with constant reactive power generation. Initially, the STATCOM operating point was around 15 Mvar, with reactive power generated only by the harmonic filters. A step function with an amplitude of 0.5 p.u. was then applied to the reactive current reference. Figure 4 shows the results obtained with a time-domain simulation program while Figure 5 presents the results obtained at the site.

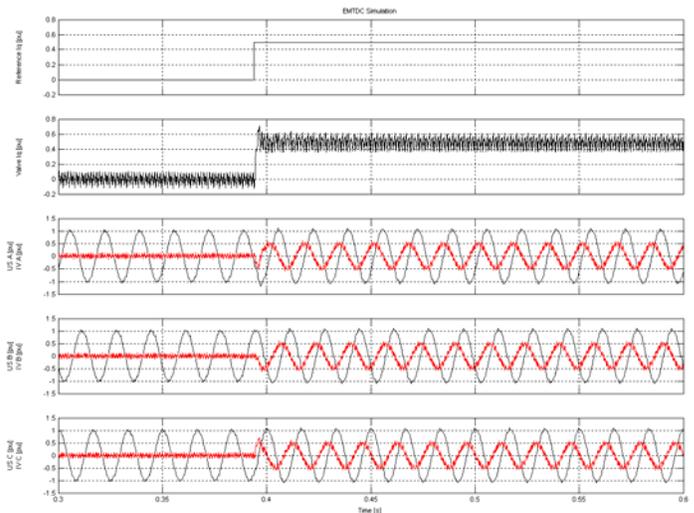


Fig. 4. 0.5 per-unit step response at reactive current reference. Time-domain simulation.

- VSC reactive current reference
- VSC reactive current instantaneous value
- VSC three-phase currents and 32 kV bus voltages

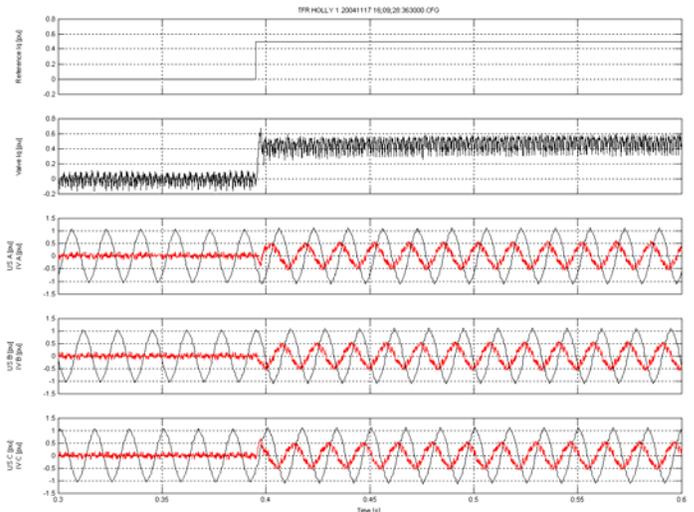


Fig. 5. 0.5 per-unit step response at reactive current reference. Test performed at site.

- VSC reactive current reference
- VSC reactive current instantaneous value
- VSC three-phase currents and 32 kV bus voltages

In addition to the consistency in the results, the plots also show the very fast response of the VSC current controller, providing thus almost instantaneous reactive power support to the system. This feature is particularly useful in the event of faults in the power system, as presented in the next section.

VI. OPERATIONAL EXPERIENCE

The Holly STATCOM was commissioned in the fall of 2004. Design and constructions activities prior to energization went smoothly and even put the project ahead of the time schedule. However, during the time following the first energization, a number of IGBTs failed virtually without any clear reason.

Fault tracing eventually determined the reasons for the high IGBT failure rate. The semiconductors are switched on and off (IGBTs) and supervised (IGBTs and diodes) via fiber optic cables. The fiber optic cables are intended to be attached to the electronic boards at the same potential. For the Holly STATCOM, the design of the light guide contact had changed from previous SVC Light projects and a metal piece of the connector now lacked a defined potential.

The electromagnetic environment inside the valve enclosure by its nature has a high disturbance level. This lead to partial discharges that sometimes delivered a false pulse to the IGBT electronics. These pulses would normally not have disturbed the electronic circuits. However, a second reason for the IGBT failures was identified. An integrated circuit was found to have different properties compared to earlier batches. A short pulse, as created by the disturbance, was prolonged and was sometimes long enough to be detected as a turn-off pulse. If this happened during a conduction interval, the IGBT position picked up a very high voltage resulting in the immediate failure of the triggered IGBT.

Both of the above reasons were mitigated with minor modifications, which were implemented on site. After a one-month trial operation, the STATCOM successfully went into commercial operation.

Some of the expected results have been reported in a previous section and in an earlier publication [9]. Here the results will be further discussed. Two cases are shown in the following that illustrate the STATCOM dynamics and performance during remote faults captured by the Transient Fault Recorder (TFR), integrated with the MACH2 control system. The high performance fault recorder can sample and trigger on any internal control signal without any external wiring.

The first case occurred during the period of tests of the control system. The benefit of the STATCOM's support to the transmission system was demonstrated during the severe thunderstorms that hit central Texas area in November 2004. There were several faults of about 5 cycle duration on the 138 kV system that resulted in the STATCOM to produce its maximum capacitive output. Figure 6 shows some plots related to one of these faults, obtained from the TFR. The capacitor bank control was disabled at the instant of the disturbance and the initial STATCOM operating point was

close to 0 Mvar.

This event showed also the need for adjusting the dead-band of the AC voltage regulator during the return of the STATCOM to its pre-fault operating point. This is verified in the third plot, corresponding to the VSC current reference signal after time $t=1$ s.

Some days later, a fault closer to the STATCOM occurred at the adjacent 69 kV system around $t = 1.0$ s in Figure 7. The bottom plot shows clearly a drop on phase B voltage at the 138 kV bus. The STATCOM responded to the voltage reduction by maximizing its capacitive output. Despite the clear unsymmetrical nature of the disturbance, reflected also to the DC side of the VSC, the VSC currents are symmetrical during the fault, which is a feature that can only be achieved by employing PWM switching. After the fault has been cleared, the current is ramped down to the initial pre-fault value in a controlled manner. The STATCOM is then ready to support the grid if a new disturbance should occur.

An additional feature in the STATCOM control is the FACTS Online web-based module used for on-line diagnostics and monitoring over the Internet. This feature in the control gives notification to selected support personnel by e-mail following minor disturbances and also by phone messages following critical disturbances. Information from the MACH2 control is made available for engineering analysis over the Internet. This includes information such as operational status of the STATCOM, event and fault information, disturbance records, etc. The benefit of on-line monitoring is that support engineers have direct access to the same diagnostic information as is available in the local Human-Machine

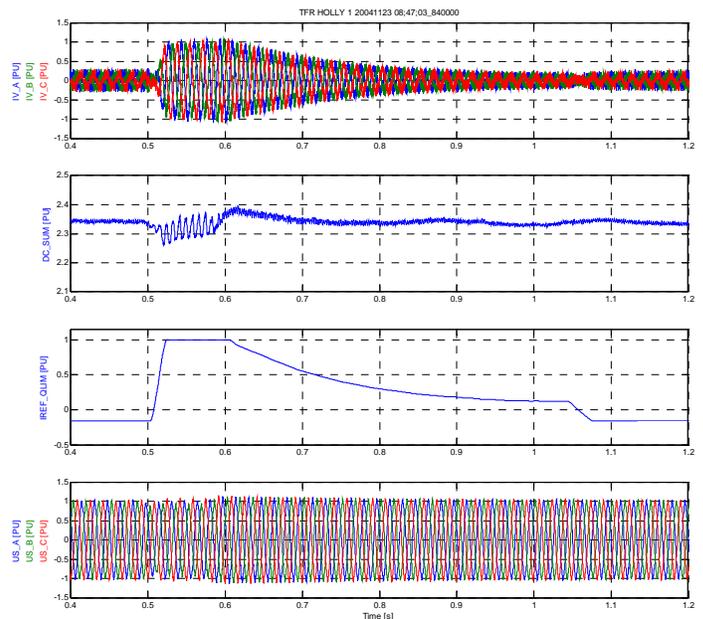


Fig. 6. Example of STATCOM response during a transmission line fault

- VSC three-phase currents
- DC voltage
- VSC reactive current reference calculated by the control system
- 138 kV three-phase voltages

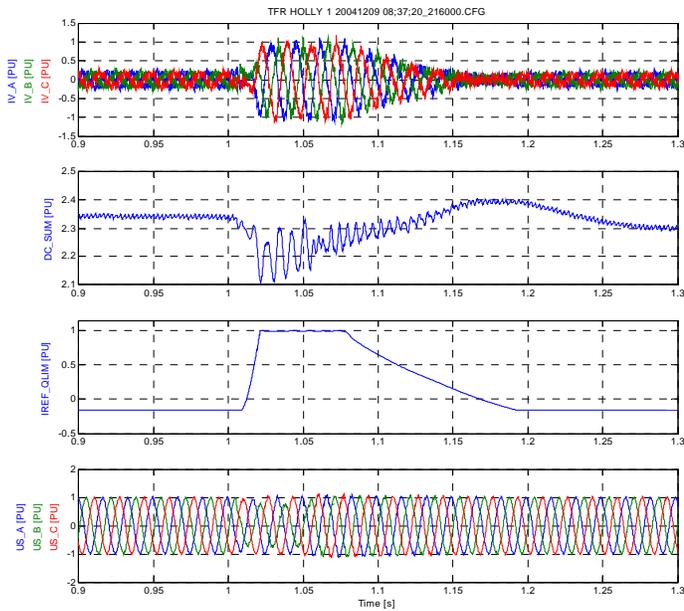


Fig. 7. STATCOM response during a fault on the adjacent 69 kV system.

- VSC three-phase currents
- DC voltage
- VSC reactive current reference calculated by the control system
- 138 kV three-phase voltages

Interface (HMI) of the MACH2 system, regardless of location should a disturbance occur. Figure 8 shows one of the FACTS Online displays available over the Internet.

Common practice for high voltage VSC, is to utilize valves containing a stack of series connected semiconductor devices in order to reach a sufficient voltage rating. Such stacks normally contain more semiconductor devices than the number required for operation in all specified conditions. The number of extra devices is used as redundant positions. If semiconductor failures occur during operation they are short-circuited and the converter can remain in operation as long as the number of failed IGBTs is less than the number of redundant positions.

Should all redundant IGBTs fail and then an additional IGBT fails, the plant would normally trip. For critical applications such as the Holly STATCOM, this is unacceptable. To continue operation beyond the redundancy, a new solution has been implemented in the Holly STATCOM. If the redundant semiconductor device fails, the DC voltage is slightly reduced to allow the remaining components to stay within their rating and operation can be maintained.

With this method, the capability of reactive power absorption by the VSC is not affected in the inductive region. However, operation in the capacitive region may be slightly reduced. The major benefit is an increased availability of the VSC and converting forced outages to deferred or planned outages.

For the five months after the start of operation, the STATCOM availability has been 100% without any forced trips due to the installation itself. The IGBT failures do have ceased and there has been no de-rating of the STATCOM.

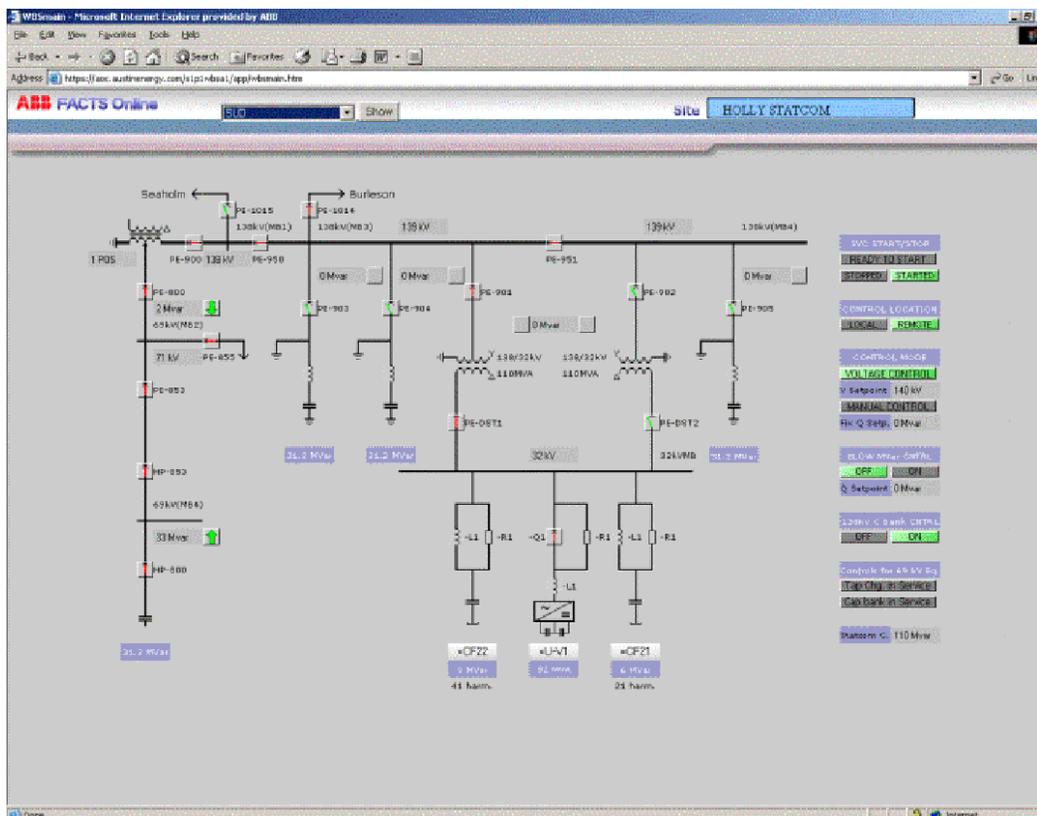


Fig. 8. FACTS on line view in an Internet browser

VII. CONCLUSIONS

As reported and demonstrated in this paper, FACTS devices can replace the dynamic reactive support of critical generation with several benefits regarding transient voltage recovery, economical and environmental aspects, operation and maintenance costs, etc. The technology is mature and provides a robust system for mitigating grid disturbances.

The Holly STATCOM has after acceptance tests shown very high performance and reliability during the initial months it has been in operation.

VIII. ACKNOWLEDGEMENT

The work and efforts of all people involved in the different phases of the project are greatly acknowledged. No one mentioned and no one forgotten.

IX. REFERENCES

- [1] R. Grünbaum, T. Gustafsson, U. Olsson, "SVC Light: Evaluation of first installation at Hagfors, Sweden", CIGRÉ conference, paper 13/14/36-03, Paris, France, 2001
- [2] T. Larsson, B. Ratering-Schnitzler, "SVC Light: A utility's aid to restructuring its grid", IEEE PES winter meeting, Singapore, Jan. 2000
- [3] R. Grünbaum, T. Gustafsson, J.-P. Hasler, T. Larsson, M. Lahtinen, "STATCOM, a prerequisite for a melt shop expansion – performance experiences", IEEE Power Tech, Bologna, Italy, 2003
- [4] R. Grünbaum, J.-P. Hasler, B. Thorvaldsson, "FACTS: Powerful means for dynamic load balancing and voltage support of AC traction feeders", Power Tech, Porto, Portugal 2001
- [5] T. Larsson, Å. Petersson, A. Edris, D. Kidd, R. Haley, F. Aboytes, "Eagle Pass Back-to-Back tie: a dual purpose application of voltage source converter technology", IEEE summer meeting, Vancouver, Canada, 2001
- [6] U. Axelsson, A. Holm, C. Liljegren, M. Åberg, K. Eriksson, O. Tollerz, "The Gotland HVDC Light project – experiences from trial and commercial operation", CIGRÉ conference, Amsterdam, The Netherlands, June 18 – 21, 2001
- [7] B. D. Railing, J. J. Miller, P. Steckley, G. Moreau, P. Bard, L. Ronström, J. Lindberg, "Cross Sound cable project second generation VSC technology for HVDC", CIGRÉ conference, Paris, France, Aug. 29 – Sept. 3, 2004
- [8] M. P. Bahrman, J. G. Johansson, B. A. Nilsson, "Voltage source converter transmission technologies – The right fit for the Application", IEEE PES general meeting, Toronto, Canada, July 13 – 18, 2003
- [9] E. John, A. Oskoui, Å. Petersson, "Using a STATCOM to retire urban generation", IEEE PCSC meeting, New York, USA, Oct. 2004

X. BIOGRAPHIES



Arastou Oskoui graduated from NED Engineering University with a Bachelor of Electrical Engineering and University of Texas at Austin with Master of Science degree in Electrical Engineering.

His employment experience includes five years with AMI Systems, six years with Lower Colorado River Authority in Relay Engineering, three years with Ralph M. Parson Engineering Consultants and for the last ten years with Austin Energy. He is currently Director of

Engineering and Technical Services at Austin Energy's Electric Service Delivery organization.



Biju Matthew graduated from Texas A&M University in College Station with a Bachelor of Science in Electrical Engineering in 1985. He received a Master of Science in Electrical Engineering from the University of Texas at Austin in 1988.

He started with Austin Energy in 1987 in the System Controls area and later joined the Transmission Planning group in 1988. He has worked in all facets on Transmission Planning, which includes participation in several ERCOT Task Forces. Since 2002, he has served as lead Transmission Planning Engineer for the group.



Jean-Philippe Hasler received his M.Sc. degree in Electrical Engineering from the Ecole Polytechnique Federale de Lausanne, Switzerland in 1986.

Mr. Hasler joined ABB in 1986 where he was developing control systems and protection algorithms for multi-terminal HVDC. Since 1993 he is conducting power system and control studies for different FACTS applications.



Marcio M. de Oliveira (M'1995) received his M.Sc. in Electrical Engineering in 1992 from the Federal University of Rio de Janeiro. He received his Ph.D. in High Power Electronics in 2000 from the Royal Institute of Technology in Stockholm, Sweden.

Mr. Oliveira joined ABB in 2000 and is working with system design and power system studies for reactive power compensation plants.



Tomas Larsson (S 1992, M 1999) received his M.Sc. in Electrical Engineering in 1991 and his Ph.D. in High Power Electronics in 1998, both from the Royal Institute of Technology in Stockholm, Sweden.

Mr. Larsson joined ABB in 1998 where he presently is involved in projects concerning Voltage Source Converters, reactive power compensation and flicker mitigation.



Åke Petersson received his M.Sc. degree in Electrical Engineering from Chalmers Institute of Technology, Gothenburg Sweden, in 1982.

Mr. Petersson joined ABB (at that time ASEA) in 1982 and has over the years held various engineering positions related to the application of power electronics in high voltage electrical systems. Presently he is focusing on the application of FACTS applications in transmission grids.



Eric M. John (M'1995) graduated from the Rensselaer Polytechnic Institute with a BS in Electric Power Engineering and Duke University's Fuqua School of Business with an MBA.

His employment experience includes three years with Westinghouse Power Generation working with Power Quality and FACTS. He joined ABB in 1998 and has worked with power quality and system design of FACTS devices. He is currently the US marketing manager for FACTS with ABB Inc. of Raleigh, North Carolina.